Climate and Human Impacts on Water Resources in Africa

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1) Introduction

The availability of fresh water is one of the most critical environmental issues of our time [Postel *et al.*, 1996]. This is particularly true in Africa where large portions of the continent are arid or semi-arid and the precipitation is highly variable. Additionally, large changes in land cover/land use and water management practices have taken place during the last 50 years including: removal of water from river systems for irrigation and consumption, degradation of forage land by over-grazing, deforestation, replacing natural ecosystems with mono-cultures, and construction of dams. The relatively large population and delicate ecosystems therefore, depend on water resources that vary greatly due to climate fluctuations and human induced changes. With increasing population and development we can expect that the pressures on existing water supplies in Africa and the vulnerability of the populations dependent upon these resources will continue to grow. Therefore, it is crucial that we improve our understanding of the variability of terrestrial hydrologic systems in Africa, and how human activities may affect those resources.

Our goal is to simultaneously quantify the relative impacts of the three major determinants of the observed changes in terrestrial hydrology in Africa since 1950

(1) climate variability
(2) land use/land cover change
(3) water management practices.

We will link satellite- and census-derived land cover and land use history, satellite observations of surface water level and area, comprehensive regional ecosystem and hydrology models, and ground based observations to assess the individual relative impacts on water resource availability since 1950.

These three images (from USGS EROS data center) illustrate the very large changes in water resources that have occurred in the Lake Chad basin and throughout much of semi-arid and arid Africa in the last few decades. Due to a combination of decreasing precipitation and increasing irrigation, the area of Lake Chad has shrunk from 25,000 km^2 to about 2500 km^2 today.

We will concentrate on four regions in semi-arid and arid Africa (1) the Niger River and its interior delta, (2) the Lake Chad/Chari River system in north-central Africa, (3) the Sudd marshlands of the Nile, and (4) the Okavango River and its interior delta in southern Africa.

The African continent with our study regions highlighted. Rivers and national boundaries are shown in black. The mean annual precipitation is shown with 500 mm/yr intervals (blue line). All of these features are located in semi-arid regions (where precipitation </= 500 mm/yr), are maintained by precipitation falling in distant humid regions, and are shared by many nations.

In all of these regions: (1) *water resources are limited and highly variable, (2) population and development pressures are already large and increasing, (3) land use and land cover changes have been significant, and (4) current or suggested future water management schemes are large in relation to the water resources and have international implications*

OBJECTIVE #1. Quantify land cover and land use history. Our first objective is to develop gridded data sets of the land use and land cover history over our four study regions for the period since 1950. These data sets will be used to gauge the scale of changes, and as the basic input to our numerical models. We already have created historical data sets of cropland change for each decade since 1950 for all of Africa. We will improve this data set and create new data sets to consider land use practices typical of Africa. In particular, we will develop the following regional data sets for 1950-2000: (1) Croplands and Pastures, (2) Irrigated land, (3) Degraded land, and (4) Potential vegetation

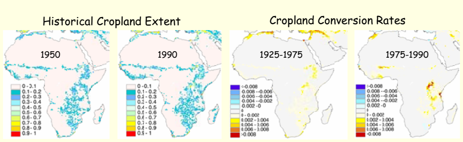


Figure 1a. The cropland extent in Africa in 1950 to 1990 (two left panels). Average rates of conversion over period shown (two right panels). The major cropland expansion during 1925-1975 occurred in the Ethiopian highlands and in Uganda, while during 1975-1990, expansion occurred mainly in Tanzania, Kenya, and Uganda, and in the western Sahel region.

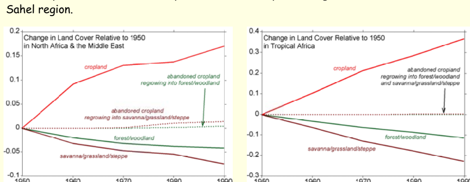


Figure 1b. Estimated changes in natural vegetation extent due to clearing for croplands. In Africa, roughly one-third of the croplands came at the expense of forests/woodlands, while nearly two-thirds came from savannas/grasslands/steppes. Very little cropland abandonment and natural vegetation regrowth occurred since 1950.

OBJECTIVE #2. Quantify current status of water resources. Water resources data sets are required to validate model simulations and to investigate hydrologic relationships within each river system. We have already collected much water resource data (*e.g., river discharge, river stage, and wetland extent*) from ground-based sources for the four target regions. We will also incorporate satellite-based information into our datasets. We will use radar altimetry, and imagery to create mean monthly time series of surface water level and extent for the major lakes and wetlands in the four target regions.

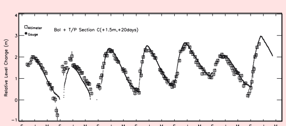


Figure 2a. Relative lake level. Lake Chad height variations from the TOPEX/POSEIDON NASA Radar Altimeter (squares) and guage data from Bol, Chad (dots). There is excellent agreement between ground and satellite based measurements. The altimeter data has been shifted by a constant amount to match the gauge heights.

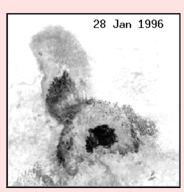


Figure 2b. NOAA/AVHRR image of Lake Chad taken on Jan 28th 1996. January is the time of maximum inundation in the Lake Chad basin. The open water is black and the vegetation and moist surfaces are in gray.

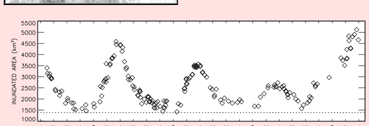
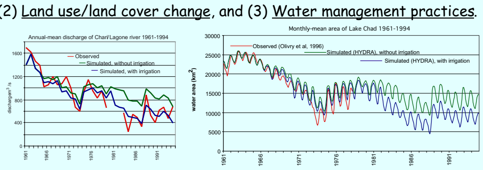


Figure 2c. Time series of open water area in the Lake Chad basin. The time series is derived by summing the open water pixels in time series of NOAA/AVHRR images such as Figure 2b.

OBJECTIVE #3. Quantify the Impact of Humans and Climate Variability on Freshwater Resources. Our third objective is to quantify the relative impact of the individual drivers of hydrological change (climate variability, land use/land cover, and water management practices) on the observed change in water resources since 1950. We will use our dynamic ecosystem model (IBIS) and our land surface hydrology model (HYDRA) in a suite of simulations forced with monthly mean climate data for the period 1950 to present. We will perform simulations of (1) Climate changes alone, (2) Land use/land cover change, and (3) Water management practices.



Simulations of the hydrology of the Lake Chad Basin (discharge at N'Djamena at left, area of Lake Chad at right are in good agreement with the observations between 1953 and 1979. After 1980, precipitation continued to be low. However, the simulated river discharge is in good agreement with observations only when large estimates of irrigation (about 10 km3/yr) are removed from the river system suggesting that water management practices have a large impact on the water budget of this basin.

OBJECTIVE #4. Evaluate Tools for Assessment of Near-Term Water Resources. Finally, we will investigate the feasibility of using our satellite tools and numerical models to assess short-term (seasonal to monthly) changes in water resources in our four regions. We feel that the accuracy of the satellite observations and numerical models are sufficient to investigate their ability to quantify current water resources. We anticipate investigating the following:

(1) Estimate seasonal flooding. Correlate the measured radar altimetry to downstream surface water area observed several months later and use this relationship to estimate the seasonal flooded extent in subsequent years.
(2) Estimate seasonal discharge. Correlate the measured radar altimetry to the simulated river height and discharge for a wide range of discharges and develop a rating curve for locations along the main rivers. This rating curve can be used to estimate seasonal river discharge in subsequent years from measured radar altimetry.